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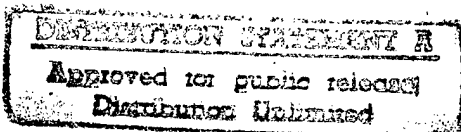
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REPORT NO T97-7

EFFECTS OF HIGH TERRESTRIAL ALTITUDE ON WORK  
PERFORMANCE IN AN NBC PROTECTIVE UNIFORM

U S ARMY RESEARCH INSTITUTE  
OF  
ENVIRONMENTAL MEDICINE  
Natick, Massachusetts

JUNE  
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USARIEM TECHNICAL REPORT 97-7

EFFECTS OF HIGH TERRESTRIAL ALTITUDE  
ON PHYSICAL WORK PERFORMANCE IN AN NBC PROTECTIVE UNIFORM

Prepared by

Stephen R. Muza, Ph.D., Ronald Jackson, Ph.D., Paul B. Rock, D.O., Ph.D.,  
James Roach, M.D., Timothy Lyons, Ph.D. and Allen Cymerman, Ph.D.

U.S. ARMY RESEARCH INSTITUTE  
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Technical Report NO. 97-7

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## BACKGROUND

Mountain environments are likely areas of military confrontation. Mountain ranges typically form the borders of nations, and numerous regions of geopolitical interest to the U.S. such as the Balkans, South America, the Middle East, and Asia contain extensive areas of moderate (>1500 m) to high (>2400 m) altitudes. Rapid force projection to such altitudes presents challenges in sustaining optimal military performance due to the hypoxia associated with altitude exposure and its deleterious affect on mission-related work activities (Tharion et al., 1992a; Malconian and Rock, 1988; Fulco and Cymerman, 1988; Cymerman and Rock, 1994). Physical tasks take longer to complete and cognitive functions are impaired. Acute mountain sickness, high altitude pulmonary and cerebral edemas, and sleep deprivation caused by hypoxia also will negatively impact performance. In addition to the high terrain, the soldier must be prepared to engage in operations in Nuclear Biological and Chemical (NBC) warfare. The wearing of NBC protective uniforms also causes degradations in military operations (Banderet et al., 1992; Taylor and Orlansky, 1993). However, the possible interactive effects of NBC protective uniform and the hypoxia of high terrestrial altitudes on physical work performance are not known. None of the applicable Army publications (FM 3-3, 3-4, 3-5, 90-6, TC 90-6-1 and TB MED 288) provide information or guidance regarding performance problems in NBC operations at moderate or high terrestrial altitudes. Assessment of cardiopulmonary function (physiological and psychological indices) under these conditions is useful in identifying limitations to soldier work performance and developing effective strategies to minimize the adverse impact of the NBC protective uniform, equipment and the high altitude terrestrial environment on military operations. This study was funded by TRADOC through the P<sup>2</sup>NBC<sup>2</sup> program.

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## EXECUTIVE SUMMARY

The wearing of nuclear-biological-chemical (NBC) protective uniforms causes a degradation in the performance of military operations (Banderet et al., 1992; Taylor and Orlansky, 1993). The magnitude of performance decrement incurred is dependent upon a complex interaction of human, mission (e.g., uniform, equipment and task), and environmental factors. Generally, wearing an NBC protective uniform produces three types of stresses to the user: thermal, respiratory and psychological. Although a considerable amount of research has been conducted examining each of these stressors in a variety of missions and thermal environments, no studies have been reported which examined physiological or perceptual responses to physical work in an NBC protective uniform in high mountain environments. Due to hypoxia, in high mountain environments there is greater stress on the cardiopulmonary system and physical work performance is decreased (Fulco and Cymerman, 1988). However, the lower air density at high altitude enhances maximal ventilatory flows (Forte et al., 1997) which may offset the NBC protective uniform's impairment to breathing. Furthermore, acclimatization to high altitude improves cardiopulmonary system function, increases oxygen delivery and improves physical work performance (Young and Young, 1988). Thus, using a staged ascent to induce altitude acclimatization may improve physical work performance in NBC protective uniforms in mountainous environments.

The purpose of this study was to test three hypotheses. First, that NBC protective uniform-induced decrements in maximal ventilatory capacities will be similar at sea level (SL) and high (H) terrestrial altitude. Second, that the decrements in physical work performance caused by wearing an NBC protective uniform will be greater at intermediate (I) and H terrestrial altitudes than at SL. Third, that staging at moderate altitude will improve work performance in the NBC protective uniform at I and H terrestrial altitudes by inducing altitude acclimatization, thus improving cardiopulmonary function. The results of this study support these hypotheses. The key findings were 1) decrements in maximal ventilatory capacities induced by the NBC protective uniform, were not altered by decreased atmospheric density at H altitude, 2) in an NBC protective uniform the physical work performance task (lift and carry) was degraded at I and H altitude but not at SL, 3) the

ventilatory and cardiac requirements to sustain the lift and carry task increased at I and H altitudes, 4) at I and H altitudes, ventilation during the lift and carry task remained a constant proportion of the individual's altitude-specific maximal voluntary ventilation, 5) rapid ascent to I altitude degraded marksmanship, and 6) following staged ascent, both physical work performance and marksmanship were improved.

The results of this study support U.S. Army recommendations (Department of the Army, Headquarters, TB MED 288, 1975) regarding the employment of a staged or slow ascent to minimize decrements in work performance and extend those recommendations to operations in NBC protective uniforms at I and H mountain altitudes.

## INTRODUCTION

The wearing of NBC protective uniforms causes a degradation in the performance of military operations (Banderet et al., 1992; Taylor and Orlansky, 1993). The magnitude of performance decrement incurred is dependent upon a complex interaction of human, mission (e.g., uniform, equipment and task), and environmental factors. Generally, wearing the NBC ensemble produces three types of stresses to the user: thermal, respiratory and psychological. Although a considerable amount of research has been conducted examining each of these stressors in a variety of missions and thermal environments, no studies have been reported which have examined the combined effect of the NBC protective uniform stresses with the hypoxic stress of a high mountain environment on physical work performance.

Military personnel deployed to high mountain areas immediately experience the consequences of the decreased ambient partial pressure of oxygen (Tharion et al., 1992a; Malconian and Rock, 1988; Fulco and Cymerman, 1988; Cymerman and Rock, 1994). The reduced oxygen content in the arterial blood decreases physical work capacity. Even at relatively moderate altitudes (~1,524 m), work performance is decreased. Above 1,524 m, maximal oxygen uptake decreases at a rate of ~10% per 1,000 m (Fulco and Cymerman, 1988). Because the absolute oxygen uptake for a given physical task will be identical at all altitudes, with increasing altitude the oxygen requirement elicited by a given physical task (e.g., approach march, preparing defensive works, etc.) represents a greater fraction of the individual's maximal oxygen uptake. However, ventilation, heart rate, cardiac output, O<sub>2</sub>-debt and perceived effort will be greater at higher altitudes due to the hypoxia. Consequently, the cardiopulmonary stress on the body will be greater to a degree that is proportional to the hypoxia-induced reduction in maximal oxygen uptake.

At high terrestrial altitudes, the ventilation required to support physical work is increased, although this increase does not entirely compensate for the decrease in the inspired oxygen partial pressure (Consolazio et al., 1968; Miles, 1957; Mekjavic et al., 1991; Hackney et al., 1992; Bebout et al., 1989; Fulco and Cymerman, 1988). Because

hypoxia is the stress at high altitude, the body's oxygen transport system (i.e., the respiratory and cardiovascular systems) is the principal system effected by the stresses associated with military operations in high mountain environments.

At low altitudes, decrements in physical work performance while wearing the NBC protective uniform have been attributed, in part, to symptoms of respiratory distress (Muza et al., 1996; Tyner et al. 1989; Banderet et al., 1992; Patton et al., 1995; Munro et al., 1986; Muza, 1986). The NBC protective uniform presents three challenges to the respiratory system: increased inspiratory resistance, added upper airway dead space, and chest wall restriction (Muza, 1986). The added inspiratory resistance of the Chemical Biological (CB) protective mask filter canister increases the work of breathing, decreases maximal breathing capacity and potentiates the development of adverse respiratory sensations (i.e., breathlessness). The CB mask adds dead space to the upper airway which must be compensated for by increasing inspired volume at rest or during exercise. Moreover, it was recently demonstrated that the multiple layers of overlying protective clothing and load bearing equipment (LBE) restrict chest wall expansion, increase the work of breathing, potentiate the development of breathlessness and decrease maximal breathing capacity, independent of the CB mask (Muza et al., 1996). At SL, the NBC protective uniform with a fragmentation protective vest and LBE configured with a fighting load reduced the soldier's maximal voluntary ventilation (MVV) by ~25% and more than double the work of breathing. Moreover, in addition to impairing ventilation, the NBC protective uniform will increase the metabolic requirements for performing a given physical task. For example, an USARIEM study found that performing a typical military task (lifting, carrying and loading of artillery shells onto a 2.5 ton truck bed) in an NBC protective uniform increased oxygen uptake by ~18% compared to the standard U.S. Army Battle Dress Uniform (BDU) (Patton et al., 1995). Thus, the NBC protective uniform not only decreases ventilatory capacity and function, but simultaneously increases ventilatory demand via increased metabolic activity.

Given the increased ventilatory demands required to perform military tasks in high mountain environments, we hypothesized that the decrements in physical work performance caused by wearing the NBC protective uniform would be greater than at lower

altitudes, and a larger proportion of the decrements would be attributed to respiratory distress.

As previously noted, upon rapid ascent to high altitudes, physical work endurance and aerobic work capacity are degraded in proportion to the reduction in arterial oxygen content (Fulco and Cymerman, 1988; Sawka and Young, 1989; Horstman et al., 1980). Furthermore, in many individuals, the stress of the hypoxic environment causes physiological dysfunctions which may be manifest in the form of several altitude illnesses, especially Acute Mountain Sickness (AMS). The natural countermeasure to these impairments is altitude acclimatization. Presumably, the body starts the acclimatization process as soon as the hypoxic stimulus is sufficient to trigger it (~1,524 m). However, the natural time course of acclimatization is such that too rapid ascent to higher altitudes will overwhelm the beneficial adaptations.

One approach to minimizing altitude-induced impairments is to use a slow or staged (temporary residence at moderate altitude) ascent profile which allows partial acclimatization. It is a widely held belief that above 2,000 m ascent should be limited to no more than ~300 m/day (Hackett, 1980; Hackett et al., 1976; Hackett and Roach, 1987), or after a rapid ascent of ~1,000 m, further ascent should be prohibited for at least 3 days. Current U.S. Army medical recommendations (Department of the Army, Headquarters, TB MED 288, 1975) dictate staging sea-level troop movements with at least 2 day stops at moderate altitudes, such as at 2,000 m, 3,000 m, etc. These recommendations are based in part on the results of previous studies of altitude illness and in part on speculation. In several studies (Hansen et al., 1967; Kobrick, 1976; Evans et al., 1976; Banderet, 1977; Stamper et al., 1980) examining staging at moderate altitudes, SL residents followed an ascent profile consisting of 2-7 day residences at 1,585 m or 3,475 m prior to attaining 4,300 m altitude. These staged-ascent profiles effectively decreased the incidence of AMS symptoms by ~70%. The authors of these studies concluded that the short-term stays at moderate altitudes presumably initiated and promoted some degree of altitude acclimatization. The assumption underlying this conclusion was that the absence or abatement of AMS was due to the physiological adaptations accompanying acclimatization. However, no measurement of these physiological adaptations were reported in any of these

studies. Consequently, aside from ameliorating AMS symptomatology, the magnitude of altitude acclimatization achieved by staging at moderate altitude is unknown.

As previously reviewed, hypoxemia is lessened with acclimatization by increasing ventilation and decreasing plasma volume, which effectively increases the blood's oxygen carrying capacity. Consequently, submaximal exercise endurance improves as altitude acclimatization progresses (Young and Young, 1988; Wolfel et al., 1991; Levine and Stray-Gundersen, 1992; Grover et al., 1986; Brooks et al., 1991a; Brooks et al., 1991b; Bender et al., 1988; Bender et al., 1989a; Bender et al., 1989b). If staging at moderate altitude initiates and promotes the acclimatization process, then some degree of the appropriate physiological adaptations to altitude (i.e., increased ventilation, decreased plasma volume, and improved tolerance to submaximal exercise) should be present immediately upon arrival at the higher altitude.

The purpose of this study was to test three hypotheses. First, that NBC protective uniform-induced decrements in maximal ventilatory capacities would be similar at sea level (SL) and high (H) terrestrial altitude. Second, that the decrements in physical work performance caused by wearing an NBC protective uniform would be greater at intermediate (I) and H terrestrial altitudes than at SL. Third, that staging at moderate altitude would improve work performance in the NBC protective uniform at I and H terrestrial altitudes by inducing altitude acclimatization, thus improving cardiopulmonary function. The specific objectives were to assess the interaction of moderate to H terrestrial altitudes and the wearing of an NBC protective uniform on 1) maximal ventilatory capacities, 2) physical work performance of selected military tasks, and 3) the associated cardiopulmonary and subjective responses. The contribution of a staged ascent at ~1,830 m on amelioration of I and H-altitude induced performance decrements following rapid deployment from SL was also assessed.

## METHODS

### SUBJECTS

Nine male test volunteers were studied, but due to scheduling conflicts, only 8 completed the entire test protocol. Subjects were active duty military personnel stationed at Natick Research Development and Engineering Center. Description of salient subject characteristics (Mean  $\pm$  S.D.) are given in Table 1.

**TABLE 1: SUBJECT CHARACTERISTICS**

Age (yr)	Height (cm)	Weight (kg)	Peak $\text{Vo}_2$ (ml/kg/min)	Body Fat (%)
21 $\pm$ 2	173 $\pm$ 5	68.8 $\pm$ 8.5	58.6 $\pm$ 13.1	14.4 $\pm$ 2.4

### STUDY DESIGN

The test schedule was designed to compare the physiological and subjective responses to physical work in BDU vs. NBC protective uniform at sea level (SL), intermediate altitude (I: 2,743 m) and high altitude (H: 4,300 m) following a rapid and staged ascent to I and H altitudes. The test protocol consisted of two phases: a SL phase conducted in the USARIEM Hypobaric Chamber Facility located in Natick, MA and a Colorado phase (Fig. 1). During the SL phase, tests were conducted at two altitudes, SL (actual altitude 50 m) and simulated 4,300 m (PB 446 mmHg) following a rapid ascent (305 m/min). The test volunteers remained at simulated H altitude  $\sim$ 3 h. At SL and H altitudes, chamber temperature and relative humidity were set to 18°C and 30%, respectively. During the Colorado phase, testing was conducted at I and H altitudes, and subjects were staged at moderate altitude (M: 1,830 m).

Seven to ten days following completion of the SL test phase, volunteers were transported by air from Boston to Colorado Springs, CO. Ground transportation was utilized in and around Colorado Springs and Pikes Peak to move test volunteers between their billets and test sites. Colorado Springs was the M altitude staging site; i.e., volunteers slept and spent the majority of their time there prior to ascending to higher altitudes. Travel to either the I or H altitude test sites took less than 1 h by car from the M altitude staging site. As shown in Fig. 1, the NBC protective uniform tests were done on the morning of the first (CO1) and fourth days (CO4) after arriving at Colorado Springs at an I altitude test site (PB 552 mmHg) on the flank of Pikes Peak. These tests were conducted under an Army GP Medium tent to minimize natural environmental disturbances (i.e., wind, solar load, precipitation). Given the morning test schedule and climate of the area, generally dry conditions (rh ~30%) with cool to moderate temperatures (Ta 15-20°C) were present during testing at this field site. However, due to equipment problems, testing was delayed following the staged ascent to I altitude and Ta was ~23°C for the latter half of that test period. Following completion of the NBC protective uniform tests on CO4, the volunteers were transported to H altitude (PB 460 mmHg) on the summit of Pikes Peak. The volunteers were housed and the final NBC protective uniform tests at H altitude were performed in the USARIEM Pikes Peak Medical Research Laboratory (Ta ~18°C, rh ~30%) on CO5. On the final test day (CO6), pulmonary function tests in all three uniforms were conducted at H altitude.

The baseline uniform consisted of the standard U.S. Army issue BDU, cotton undergarments and combat boots (total weight 3.6 kg). The NBC protective uniform (U.S. Army Mission Oriented Protective Posture IV) was the standard U.S. Army issue Battle Dress Overgarment (BDO) including boots, gloves and the M40 CB mask with the C2 filter canister (total weight 3.3 kg). The BDO was worn over the BDU. Additionally, over the BDU and NBC protective uniforms, the volunteer wore a protective vest (Body Armor, Fragmentation, Protective Vest, Ground Troop) and LBE (pistol belt with suspenders) configured with a fighting load minus a weapon. This load consisted of 2 full canteens and 2 ammo carriers, each loaded with the equivalent of 4 full 5.56 mm 30-round magazines. The combined weight of the protective vest, LBE, full canteens, and ammo carriers was ~10.5 kg. These two uniform/equipment configurations were selected because both are commonly used in the field, and this NBC protective uniform combination was recently

demonstrated to reduce MVV by ~25% (Muza et al., 1996). For the NBC protective uniform test, a U.S. Army M40 CB mask with C2 filter canister, but without a hood, was modified for the collection of expired gases by an ambulatory metabolic measurement device (Oxylog, P.K. Morgan Ltd.). During the test in BDU, a standard, half-face piece, exercise testing mask (Rudolph Inc., model 7910) was used for expired gas analysis by the Oxylog. In order to assure a proper seal between the masks and face, no helmet or hood was worn.

## **TEST PROCEDURES**

### **1. Pulmonary Function Tests**

These measures were made to characterize the volunteer's pulmonary function at SL and H altitude and the degree of impairment resulting from wearing the NBC protective uniform at each altitude. Three uniform configurations were tested to delineate between the impact of the CB Mask and torso loads on pulmonary function: the unrestrictive PT uniform (PTU), the BDU uniform with LBE (torso load, no CB Mask), and the NBC protective uniform with LBE (torso load and CB Mask). All tests were performed using a computer-controlled, dry-rolling seal spirometry system (SensorMedics 2450 PFT System) and met appropriate reproducibility criteria (Gardner et al., 1987). Measured variables in all three uniforms at SL and H altitude included: Forced Vital Capacity (FVC), Forced Expired Volume 1 sec (FEV<sub>1</sub>), Forced Inspiratory Flow 50% (FIF50%), Forced Expiratory Flow 50% (FEF50%), and MVV. The PFTs were performed in the morning and prior to any exercise. At H altitude the PFTs were done on the morning of CO6. To insure each subject had normal pulmonary function, at SL in the PTU only, lung volumes by helium dilution, and diffusion capacity by the single breath carbon monoxide technique, were measured.

### **2. Military Occupational Tasks**

The volunteers performed two common military tasks in sequence: 1) a lift and carry task (dummy 105 mm round, ~ 25 kg), carried 10 m and placed on a shelf, 132 cm above the ground, simulating the tailgate of a 2.5 ton truck, and 2) a marksmanship task (M-16 rifle). In order to minimize variability in the performance of these tests, volunteers received several days of training, in both BDU and NBC uniforms. Testing was normally completed

prior to 1300 h. The volunteers performed the lift and carry task for a maximum of 10 minutes at the rate of 4 lifts and carries per minute. Cardiopulmonary and metabolic parameters were measured from the standing volunteer prior to the start of the task and every 2 minutes throughout the work bout (Table 2). Measured physiological variables included minute ventilation (VE) and oxygen uptake ( $\text{Vo}_2$ ) acquired by the ambulatory metabolic measurement device (Oxylog, P.K. Morgan Ltd.); arterial saturation ( $\text{SpO}_2$ ) by finger pulse oximeter (Oxyshuttle, SensorMedics Corp.); and heart rate (HR) by electrocardiography (UNIQ Heartwatch, Computer Instruments Corp.). Simultaneous with the physiologic recordings, the volunteers were asked to rate their perception of exertion using the 16-point Borg Scale (Borg, 1973). Immediately after the lift and carry task and just prior to the marksmanship task, two questionnaires were administered to evaluate the volunteers' subjective reactions: the Environmental Distress Questionnaire (Table 7) and the Internal States Questionnaire (Table 8).

Since the occurrence of heat strain is commonly a limiting factor to exercise performance in an NBC protective uniform and may confound assessment of terrestrial altitude effects, heat strain was minimized by limiting the physical work tasks to 10 min and total encapsulation in the NBC uniform to 25 min for each trial with at least 2 h rest between trials. Furthermore, to minimize deleterious effects of dehydration, volunteers drank ~400 ml of water ~30 min before the start of each military occupational task test scenario and were encouraged to drink fluids and snack during their rest period.

Volunteers performed a marksmanship task immediately after completing the questionnaires following the lift and carry task. Marksmanship was quantified with a laser marksmanship training device (Noptel ST-1000, Oulu, Finland) attached to a deactivated M-16 rifle. The volunteers shot from a free-standing, unsupported position at a 2.3 cm diameter circular target 5 m away. This task simulated a 46 cm diameter target at 100 m, which is similar to the standard 49 cm wide, 100 m military silhouette man. For the first 10 shots, volunteers were instructed to shoot as quickly as possible, without sacrificing accuracy, after a light adjacent to the target was illuminated. For the second 10 shots, volunteers were instructed to fire at will to obtain the best accuracy score possible. When wearing the BDU uniform, volunteers removed the half-face piece mask prior to initiating

the marksmanship task. During each test session, each volunteer performed the lift and carry and marksmanship task twice: once in the BDU and once in the NBC protective uniform, with ~2 h rest between trials. The order of trials (NBC vs. BDU) was counterbalanced across all volunteers.

**TABLE 2: MILITARY OCCUPATIONAL TASKS TEST SCENARIO**

Time (min)	-10	0 - 10	10 - 13	13 - 23
Activity	Baseline Physiologic & Subjective Assessments	Lift and carry Task (physiologic monitoring)	Post-task Subjective Assessment	Marksmanship Task

### **3. Subjective Assessment**

During each *Military Occupational Tasks* test, evaluation of each volunteer's subjective reactions was performed using 1) The Environmental Distress Questionnaire (EDQ), 2) The Internal States Questionnaire (ISQ), and 3) the Borg Scale. An investigator orally announced items from the EDQ and ISQ to the volunteers, then paused briefly for the volunteer to announce their rating for that item. Prior to initiating actual testing, the volunteers were given the questionnaires once for familiarization. Both questionnaires had been previously used to assessment NBC protective uniform and exercise effects on subjective reactions (Muza et al., 1996). The EDQ and ISQ were administered just prior to initiating the lift and carry task test and immediately after completing the lift and carry task. The pre-task questionnaires were analyzed to determine if uniform or altitude had any significant effect on resting subjective reactions. The post-task questionnaires were analyzed to determine if uniform or altitude had any significant effect on subjective reactions during the lift and carry task.

**A. Environmental Distress Questionnaire**--The EDQ consists of 24 of the 67 items in the Environmental Symptoms Questionnaire (Shukitt et al., 1990; Sampson et al., 1983). The EDQ results from combining all items from The General Distress Index (Munro et al., 1986) and The Subjective Heat Illness Index (Johnson and

Merullo, 1993). The General Distress Index predicts soldiers who are less likely to complete a stressful challenge in NBC (Munro et al., 1986). The Subjective Heat Illness Index quantifies the effects of heat and dehydration (Derogatis, 1983). In the present study, attempts were made to avoid high ambient heat and dramatic increases in body temperature. So many of the "heat" items served as positive controls and diverted attention from items of greatest interest in this study.

**B. Internal States Questionnaire**--The ISQ consists of 28 items to assess subjective reactions to ventilation. Items reflecting both pleasant and aversive effects were incorporated to minimize response bias and stereotypy (Banderet et al., 1990). The ISQ uses a 6-point rating scale with discrete-anchor points that is the same as that used with the EDQ and the original Environmental Symptoms Questionnaire.

**C. Borg Scale**--The 15-point Borg Scale (Borg, 1973) was used to assess the subjects' overall perception of exertion during the lift and carry task. The subjects were asked to rate their perception of exertion by pointing to the appropriate rating on the scale, at 2-min intervals during the lift and carry task.

#### **4. Peak Oxygen Consumption**

These studies assessed the aerobic fitness of the test volunteers and provided reference values for expressing the relative intensity (%  $\text{VO}_{2\text{peak}}$ ) of each individual's work rate during the lift and carry task. Volunteers performed this exercise test in their PTU. Each volunteer completed two  $\text{VO}_{2\text{peak}}$  tests in the hypobaric chamber; once at SL and, on another day, once at H altitude after a rapid ascent. The  $\text{VO}_{2\text{peak}}$  was determined by employing a continuous effort, progressive intensity, treadmill exercise protocol. In this protocol, speed was held constant at either 5 or 6 mph. Initial treadmill grade was 0. Grade was increased by 2.5% every 100 sec until the volunteer reached exhaustion. During the last 20 sec at each grade, measurements of HR (Schiller, Cardiovit AT-6),  $\text{SpO}_2$ , and  $\text{VO}_2$ , carbon dioxide output ( $\text{VCO}_2$ ), and VE (SensorMedics Corp. model MMC 2900 metabolic measurement cart) were recorded.

## **5. Data Analysis**

The data were analyzed using a computer-based statistical analysis program (SigmaStat for Windows, Jandel Scientific, Inc.). Data are reported as means  $\pm$  standard deviation. A three-way ANOVA was used to determine the effect of altitude, time-at-altitude (staging) and MOPP uniform levels on task performance, physiological and psychological variables. The mean group values were compared using the Student-Newman-Keuls test. Tests of possible relationships between variables were performed using the Pearson Product-Moment Correlation method. For all statistical procedures, significance was accepted at  $p < 0.05$ .

# **RESULTS**

## **PULMONARY FUNCTION TESTS**

*Uniform effects:* The measurement of pulmonary function provided a quantitative assessment of the respiratory load produced by wear of each uniform combination. The BDU with LBE had negligible effects on airflows or lung volume (Table 3). On the other hand, the M40 CB mask significantly decreased respiratory flow (FIF50%), and the additional clothing layers of the NBC protective uniform decreased FVC (Table 3). Compared to the PT uniform, the NBC protective uniform configuration decreased MVV by about 33% (Table 3).

*Altitude effects:* In general, respiratory flows (FIF50%, FEF50%) increased at H altitude. The MVV was significantly increased at H altitude in all uniform combinations (Table 3). The overall effect of H altitude was to increase MVV by about 30% above SL. The increased MVV was mostly attributed to an increase in inspiratory flow rates (FIF50%). Figure 2 illustrates the decrement in these fundamental measures of pulmonary function produced by the NBC protective uniform at SL and H altitude. The NBC protective uniform produced proportionally similar ventilatory decrements at SL and H altitude (Table 3).

**TABLE 3: EFFECT OF UNIFORM AND ALTITUDE  
ON MAXIMAL PULMONARY FUNCTION**

VARIABLE	ALT	PTU	BDU	NBC
FVC (l)	SL	5.43±0.90	5.33±0.81	4.77±0.71*†
	H	5.40±0.84	5.35±0.94	5.22±0.76‡
FEV <sub>1</sub> (l)	SL	4.53±0.90	4.69±0.78	4.34±0.69
	H	4.97±0.96	4.80±1.06	4.68±0.94
FEV <sub>1</sub> /FVC	SL	0.83±0.09	0.88±0.06	0.91±0.04
	H	0.92±0.07	0.89±0.09	0.89±0.08
FEF50%(l·s <sup>-1</sup> )	SL	5.80±1.51	5.97±1.09	5.70±0.94
	H	7.24±1.77‡	6.91±2.37	6.84±1.81
FIF50% (l·s <sup>-1</sup> )	SL	6.87±1.24	6.11±2.02	4.61±0.69*†
	H	9.23±2.74‡	8.58±2.66‡	5.26±0.87*†
MVV (l·min <sup>-1</sup> )	SL	180±27	174±35	121±22*†
	H	234±40‡	221±40‡	152±21*†‡

P<0.05: \* vs. PTU; † vs. BDU; ‡ H vs. SL

### LIFT AND CARRY TASK: CARDIOPULMONARY RESPONSES

*Uniform effects:* The NBC protective uniform did not significantly decrease the number of munitions lifted and carried within the 10 min task duration (Fig. 3). However, the NBC protective uniform did significantly increase the physiologic strain. The  $\dot{V}O_2$ ,  $\dot{V}E$ , and HR were significantly greater during the lift and carry task (Table 4) when wearing the NBC protective uniform compared to the BDU. The  $\dot{V}O_2$ , averaged over the last 6 min of the lift and carry task, was ~8.5% higher ( $p<0.05$ ) in the NBC protective uniform (Fig. 4). The oxygen uptake of the lift and carry task as a percentage of the SL  $\dot{V}O_{2peak}$  was  $41\pm7\%$  and  $45\pm7\%$  in the BDU and NBC uniforms, respectively. Consequently,  $\dot{V}E$  (Fig. 5) and HR (Fig. 6) were also higher ( $p<0.02$ ) in the NBC protective uniform. However, when normalized for the  $\dot{V}O_2$  ( $\dot{V}E/\dot{V}O_2$ , Fig. 7),  $\dot{V}E$  was not altered by the NBC protective uniform (Table 4). But when the  $\dot{V}E$  was expressed as a percentage of the uniform specific MVV

( $\dot{V}E/MVV$ ), the NBC protective uniform required a greater percentage ( $p<0.02$ ) of the subject's MVV to perform the physical work (Fig. 8).

*Altitude effects:* In general, ascent to I and H altitudes significantly increased the physiologic strain and decreased physical work performance. At standing rest prior to starting the lift and carry task, HR was higher and  $SpO_2$  lower at I and H altitudes in both uniforms (Table 5). The number of munitions carried (Fig. 3) was significantly less at H altitude, particularly in the NBC protective uniform, although the uniform differences were not significant ( $p=0.14$ ). The  $\dot{V}O_2$  was significantly greater ( $p<0.02$ ) at I altitude in both uniforms (Fig. 4). This greater  $\dot{V}O_2$  at I was possibly the result of performing the lift and carry task on a rough, short grass, and gravel surface, whereas the SL and H altitude studies were performed on hard smooth floors. The oxygen uptake of the lift and carry task as a percentage of the H altitude specific  $\dot{V}O_{2peak}$  was  $58\pm 8\%$  and  $62\pm 8\%$  in the BDU and NBC protective uniforms, respectively. In both uniforms, at I and H altitudes,  $\dot{V}E$  (Fig. 5) and HR (Fig. 6) were higher ( $p<0.02$ ), and  $SpO_2$  (Fig. 9) and  $O_2$  Pulse (Fig. 10) lower ( $p<0.02$ ) than at SL. During the lift and carry task, desaturation occurred ( $p<0.05$ ) in both uniforms at I and H altitudes. When minute ventilation was normalized for  $\dot{V}O_2$ , the  $\dot{V}E/\dot{V}O_2$  showed (Fig. 7) a progressive increase ( $p<0.02$ ) from SL to I and H altitudes. However, when the  $\dot{V}E$  was expressed as a percentage of the uniform and altitude specific MVV ( $\dot{V}E/MVV$ ), increasing altitude did not alter the percentage of MVV required to perform the physical work in either uniform (Fig. 8).

*Staged Ascent effects:* Due to large intersubject variability in work performance, no statistically significant differences were found between staged (SI or SH) vs. rapid (RI or RH) ascent to I and H altitudes. As illustrated in Fig. 3, several trends are evident. More munitions were carried after staged ascent in the NBC protective uniform at I altitude and in both uniforms at H altitude. In the BDU, following staged ascent to H altitude, 3 more subjects completed the lift and carry task (Table 6). However, staged ascent to H altitude provided less physical work improvement in the NBC protective uniform. Following staged ascent to I altitude, both  $SpO_2$  (Fig. 9) and  $O_2$  Pulse (Fig. 10) were significantly improved, but  $\dot{V}E$  (Fig. 5 & 7) and HR (Fig. 6) were unchanged in either uniform.

**TABLE 4. PERFORMANCE & CARDIOPULMONARY PARAMETERS DURING LIFT AND CARRY TASK: MAIN EFFECTS OF UNIFORM AND ALTITUDE**

Parameter	Statistically Significant Effects		
	Uniform	Altitude	Interaction
# Munitions Carried		++	
VO <sub>2</sub>	++	++	
VE	++	++	
VE/VO <sub>2</sub>		++	
VE/MVV	++		
SpO <sub>2</sub>		++	
HR	++	++	+
O <sub>2</sub> Pulse		++	

Each "+" indicates statistical significance at  $p < 0.05$ . Each "++" indicates statistical significance at  $p < 0.02$ . Significant items indicate that NBC protective uniform produced greater aversive changes than BDU, higher altitude increased stressful effects, or that the interaction of these effects was significant.

**TABLE 5: EFFECT OF UNIFORM AND ALTITUDE ON RESTING CARDIOPULMONARY STATUS**

VARIABLE	UNI	SL	I		H	
			R	S	R	S
VE/VO <sub>2</sub>	BDU	34±5	38±7	28±4*	34±8	33±7
	NBC	33±5	32±5	33±6	35±14	38±8
SpO <sub>2</sub> (%)	BDU	97±1	92±2*	92±1*	82±8*	83±6*
	NBC	96±1	90±2*	92±1*	81±5*	84±3*
HR (b·min <sup>-1</sup> )	BDU	78±11	102±12*	100±7*	92±8*	101±11*
	NBC	85±11	110±12*	107±9*	103±10*	103±19*

SL, sea level; I, intermediate altitude; H, high altitude; R, rapid ascent; S, staged ascent

\*:  $P < 0.05$ , vs. SL

**TABLE 6. NUMBER OF SUBJECTS COMPLETING LIFT AND CARRY TASK  
IN BDU AND NBC PROTECTIVE UNIFORMS AT EACH ALTITUDE**

Uniform	SL	RI	SI	RH	SH
BDU	8/8	8/8	8/8	5/8	8/8
NBC	8/8	6/8	7/8	5/8	6/8

SL, sea level; RI, rapid ascent to intermediate altitude; SI, staged ascent to intermediate altitude; RH, rapid ascent to high altitude; SH, staged ascent to high altitude

### **LIFT AND CARRY TASK: SUBJECTIVE REACTIONS**

The uniform type (NBC vs. BDU) and/or the altitude significantly increased many symptoms and adverse effects as measured by the Borg Scale (Fig. 11), the EDQ (Table 7), and the ISQ (Table 8). As shown in Fig. 11, the rating of perceived exertion (RPE) over the last 4 min of the lift and carry task was significantly higher ( $p < 0.05$ ) as altitude increased and in the NBC protective uniform at all altitudes. Staging did not decrease the subject's perception of effort to perform the lift and carry task at I or H altitudes.

The EDQ did not show any significant effects attributable to the uniform, but did find many effects of altitude and, in many instances, interactive (multiplicative) effects were found (Table 7). The altitude effects were related to those typically associated with hypoxia: lightheadedness, dizziness, headache, and breathlessness. A thermal sensation (sweating) was also related to altitude and appeared to be primarily related to the SI day when the early morning studies were delayed and ambient temperatures were elevated as noted in the methods.

The ISQ (Table 8) found only two uniform effects and one altitude effect, although numerous interactive effects were measured. The aversive effects of the NBC protective uniform were significant for items 17 (I am [not] relaxed) and 18 (this condition requires extra effort to breathe). Item 5 (I think I can [not] "get thru" these conditions for an additional 30 min or more) demonstrated an altitude effect. Statistically significant interactive effects measured by the ISQ generally indicated that the subjects felt poorly, and had less

endurance in the NBC protective uniform, but with no clear relationship to increasing altitude.

## MARKSMANSHIP TASK

*Uniform effects:* The NBC protective uniform significantly decreased several parameters of marksmanship performance (Table 9). The aversive effects of wearing an NBC protective uniform was greatest on the un-timed "fire-at-will" tests. The average distance from the target center (AVDIST) increased in the NBC protective uniform during un-timed tests and tended ( $p < 0.07$ ) to be greater during timed fire. Consequently, total points were lower in the NBC protective uniform during un-timed fire (Fig. 12A) and tended ( $p < 0.07$ ) to be lower during timed fire (Fig 12B). On the other hand, having just completed the physically intense lift and carry task in either uniform did not degrade marksmanship performance from the resting baseline SL (SLrest) tests.

*Altitude effects:* Due to instrument failure, marksmanship performance at H altitude was not measured. In general, ascent to I altitude significantly decreased marksmanship performance in both the BDU and NBC protective uniforms (Table 9). Significant altitude effects were present in both the timed and un-timed marksmanship tests. The AVDIST increased and the total points decreased (Fig. 12) at I altitude. There was no interaction between uniform and altitude (Table 9) on marksmanship performance.

*Staged Ascent effects:* As shown in Figure 12, staging to I altitude improved marksmanship performance in both uniforms. After staging, marksmanship performance at I altitude was not significantly different from SL.

**TABLE 7. ENVIRONMENTAL DISTRESS QUESTIONNAIRE. THE STATISTICAL SIGNIFICANCE OF EFFECTS ATTRIBUTABLE TO THE TYPE OF UNIFORM, ALTITUDE, OR THE INTERACTION OF UNIFORM AND ALTITUDE IS ALSO NOTED**

Items from the Environmental Distress Questionnaire	Statistically Significant Effects		
	Uniform	Altitude	Interaction
1. I feel lightheaded.		+	+
2. I have a headache.		+	
3. I feel dizzy.		+	+
4. I feel faint.			
5. My coordination is off.			+
6. I'm short of breath.			+
7. It's hard to breathe.		+	+
8. It hurts to breathe.		+	
9. My heart is beating fast.			+
10. I have muscle cramps.			
11. I have stomach cramps.			
12. I feel weak.			
13. I feel sick to my stomach (nauseous).			
14. I'm constipated.			
15. I feel warm.			+
16. I'm sweating all over.		+	+
17. Parts of my body feel numb.			
18. My vision is blurry.			
19. I've lost my appetite.			
20. I feel sick.			
21. I'm thirsty.			+
22. I feel tired.			
23. I feel irritable.			
24. I feel restless.			

Each "+" indicates the effect was statistically significant at  $p < 0.05$ .

**TABLE 8. INTERNAL STATES QUESTIONNAIRE. THE STATISTICAL SIGNIFICANCE OF EFFECTS ATTRIBUTABLE TO THE TYPE OF UNIFORM, ALTITUDE, OR THE INTERACTION OF UNIFORM AND ALTITUDE IS ALSO NOTED**

Items from the Internal States Questionnaire	Statistically Significant Effects		
	Uniform	Altitude	Interaction
1. I feel "claustrophobic."			
2. I can [not] easily exhale the air from my lungs.			
3. I feel anxious.			
4. My lungs hurt.			
5. I think I can [not] "get thru" these conditions for an additional 30 minutes or more.		+	+
6. I [do not] feel "great."			+
7. I feel I can not continue much longer.			
8. I [do not] feel as good as I usually feel.			+
9. I feel tense.			
10. My chest feels like it does when I have a cold or infection.			
11. My mental activities and bodily movements are [not] well coordinated.			+
12. My vision is not as good as usual.			
13. When I breathe, I feel like I can not get enough air.			
14. I [do not] like this experience.			
15. It feels like I have "butterflies in my stomach."			
16. I am [not] breathing the way I usually do.			+
17. I am [not] relaxed.	+		+
18. This condition requires extra effort to breathe.	+		
19. I feel "tingling" on some parts of my body.			
20. I am [not] coping well with these conditions.			+
21. I am [not] "in touch" with the different parts of my body.			
22. It is hard to get my body to do what I want.			
23. This situation [does not] seem easy enough to endure.			+
24. My memory and attention are [not] functioning as well as usual.			
25. It feels like I can not breathe fast enough.			+
26. I [do not] like these conditions.			
27. I feel like I'm suffocating.			
28. I am uncomfortable.			

Each "+" indicates statistical significance at  $p < 0.05$ . Significant items indicate that NBC protective uniform produced greater aversive changes than BDU, greater altitude increased stressful effects, or that the interaction of these effects was significant.

**TABLE 9. MARKSMANSHIP PERFORMANCE:  
MAIN EFFECTS OF UNIFORM AND ALTITUDE**

		Statistically Significant Effects		
Parameter		Uniform	Altitude	Interaction
AVDIST	TIMED		+	
	UN-TIMED	++	+	
AREA	TIMED			
	UN-TIMED			
HDEV	TIMED			
	UN-TIMED			
VDEV	TIMED			
	UN-TIMED			
TOTPTS	TIMED		+	
	UN-TIMED	++	+	
TIME	TIMED			

Each "+" indicates statistical significance at  $p < 0.05$ . Each "++" indicates statistical significance at  $p < 0.02$ . Significant items indicate that NBC protective uniform decreased performance compared to BDU, or that I altitude decreased performance in either uniform.

## DISCUSSION

This study tested three hypotheses. First, that NBC protective uniform-induced decrements in maximal ventilatory capacities would be similar at sea level (SL) and high (H) terrestrial altitude. Second, that the decrements in physical work performance caused by wearing an NBC protective uniform would be greater at intermediate (I) and H terrestrial altitudes than at SL. Third, that staging at moderate altitude would improve work performance in the NBC protective uniform at I and H terrestrial altitudes by inducing altitude acclimatization, thus improving cardiopulmonary function. The results of this study support these hypotheses. The key findings were 1) the NBC protective uniform induced decrements in maximal ventilatory capacities were not altered by decreased atmosphere density at H altitude, 2) in the NBC protective uniform, the physical work performance task

(lift and carry) was degraded at I and H altitudes but not at SL, 3) the ventilatory and cardiac requirements to sustain the lift and carry task increased at I and H altitudes, 4) at I and H altitudes, ventilation during the lift and carry task remained a constant proportion of the individual's altitude-specific MVV, 5) rapid ascent to I altitude degraded marksmanship, and 6) following staged ascent, both physical work performance and marksmanship were improved at I and H altitudes.

Previously (Muza et al., 1996), we reported that wearing an NBC protective uniform with body armor and LBE reduced MVV by ~25% at SL. In the current study, the decrement was ~32%. Most of the reduction in MVV in the current study was due to increased air flow resistance by the CB mask, with a small component due to chest wall restriction by the multilayered uniform. With increasing altitude, atmosphere density decreases and air flow resistance drops proportionally. At H altitude in the PTU, MVV increased about 30% over SL measures. This is comparable to previous reports (Consolazio et al., 1968; Rahn and Hammond, 1951; Forte et al., 1997). However, we were not certain to what extent the NBC protective uniform would impede maximal ventilation at H altitude. Where as the decreased gas density should permit increased flows, MVV is influenced by several other factors. For instance, maximal inspiratory flow is constrained by the force-velocity behavior of the respiratory muscles. Moreover, flow reversal is dependent, in part, on rate of change of muscle force and velocity of shortening. Finally, thoracic gas compliance is greater at H altitude. Thus, gas compression and decompression are greater and initiation of flow is delayed. Therefore, it was possible that decreasing gas density at H altitude might not improve maximal ventilatory capacities when wearing an NBC protective uniform. Our results indicate that the NBC protective uniform induced decrements in maximal ventilatory flows and volumes were similar at SL and H altitudes. Or conversely, the increase in MVV from SL to H altitude was proportionally the same in the BDU and NBC protective uniforms. This suggests that up to an altitude of at least 4,300 m, the principal impairment to ventilation by the NBC protective uniform is the air flow resistance produced by the CB mask. This means the NBC protective uniform components (mask, clothing) do not interact in any significant way to alter the relationship between gas density and air flow resistance.

Wearing an NBC protective uniform can significantly impair a wide range of military tasks (Patton et al., 1995). Even in the absence of a degradation of physical work performance, performing a task in the NBC protective uniform increases the physiologic and psychologic costs (Banderet et al., 1992; Patton et al., 1995). Given the increased cardiopulmonary demands required to perform physical work in H mountain environments, we hypothesized that the decrements in physical work performance caused by wearing the NBC protective uniform are greater than at lower altitudes due to less cardiopulmonary reserve. The results support a greater physical work performance decrement at I and H altitudes. Wearing the NBC protective uniform did not decrease the lift and carry task performance at SL, although  $\text{VO}_2$ , HR and VE were increased to varying degrees. These results are consistent with those previously reported for this task (Patton, J.F. et al., 1995). However, following rapid ascent to I altitude, performance declined in the NBC protective uniform, although there was no performance decrement in the BDU. Rapid ascent to H altitude decreased lift and carry task performance in both uniforms, although the decrement tended to be greater in the NBC protective uniform. These results support our hypothesis that hypobaric hypoxia accentuates the NBC protective uniform's degradation of physical work performance.

We believed that the physical performance decline at I and H altitudes in the NBC protective uniform would be related to hypoxic-induced strain on the cardiopulmonary system, and less reserve. Our data generally support that hypothesis. At I and H altitudes, resting  $\text{SpO}_2$  was lower and HR higher than at SL prior to onset of the lift and carry task. During the lift and carry task, at I and H altitudes, there was a further drop in  $\text{SpO}_2$ , and HR was significantly higher than at SL in both uniforms. The desaturation at I and H altitudes was significant in both uniforms, but tended to be slightly greater in the NBC protective uniform, though not statistically significant. The HR during the lift and carry task was higher in the NBC protective uniform at all altitudes, a further indication of increased stress. The desaturation during the lift and carry task at I and H altitudes accentuated the hypoxia, presumably worsening oxygen delivery to the exercising muscles and decreasing performance. Simultaneously, the elevated HR decreased cardiac efficiency as measured by the lower  $\text{O}_2$  pulse. Furthermore, there was a greater work of breathing due to the hypoxic stimulation of VE. Taken together, these indices of cardiopulmonary function indicate that performing the lift and carry task at I and H altitudes required a greater fraction

of the cardiopulmonary system capacity, and the NBC protective uniform acted to both increase the demand on the cardiopulmonary system while simultaneously decreasing ventilatory capacity.

An unexpected finding was that the  $\dot{V}_E$  during the lift and carry task remained a constant proportion of the individual's altitude specific MVV in either uniform. At the I and H altitudes, two independent factors probably promoted an increase in ventilation: hypoxic stimulation of the peripheral chemoreceptors and decreased atmospheric density. Assuming a normal hypoxic ventilatory response of  $0.4 \text{ l} \cdot \text{min}^{-1} \cdot \%^{-1}$  ( $\Delta \dot{V}_E \bullet \Delta \text{SpO}_2^{-1}$ ), at a  $\text{SpO}_2$  of 92 and 82% (i.e., resting mean  $\text{SpO}_2$  at I and H altitudes, respectively), hypoxic stimulation should have increased exercise  $\dot{V}_E$  by  $\sim 2.5$  and  $6.5 \text{ l} \cdot \text{min}^{-1}$  at I and H altitudes, respectively. The measured increase was nearly twice as much (Fig. 7). This finding is consistent with previous reports (Hussain et al., 1985; Dempsey et al., 1984) that under normoxic conditions, decreasing inspired gas density increases ventilation during cycle exercise at workloads ranging from 50 to 230 W. In fact, those authors (Hussain et al., 1985) concluded that the load compensatory mechano-responses may have prevailed over the chemosensitivity feedback effects resulting from the ensuing hypocapnia. Our results suggest a similar response with a more complex submaximal exercise task. The constant relationship between exercise ventilation and each individual's altitude specific MVV, which rose proportionately the decrease in atmospheric density, suggests that about half of the increased  $\dot{V}_E$  at I and H altitudes was due to decreased air flow resistance.

In addition to evaluating physical work performance, we used a common military task, marksmanship, to assess uniform and altitude effects on visual target acquisition, and motor skills. A previous study, conducted at low altitude, had reported decreased marksmanship performance in the NBC protective uniform (Tharion et al. 1992b). The only prior study (Tharion et al., 1992a) to examine the effects of rapid ascent and acclimatization to H altitude on marksmanship reported a substantial decline in marksmanship performance at 4,300 m in the BDU. Our results concur with those previous findings regarding both the uniform and altitude effects. It is surprising that the relatively moderate hypobaria (PB 552 mmHg) present at 2,743 m was sufficient to negatively impact

marksmanship performance (Fig. 12) in both uniforms. The decreased total scores were due to an increased distance from the center of impact of the shot group to the center of the target (bull's eye). Nonsignificant increases in both the horizontal and vertical deviations contributed to the lower scores in both uniforms at I altitude. However, unlike the previous study performed at H altitude (Tharion et al., 1992a), during timed fire, neither altitude nor the NBC protective uniform affected the sighting time.

This study demonstrated that staging at moderate altitude will improve work performance at I and H terrestrial altitudes. Following the staged ascent, physical work performance was improved at I and H altitudes and marksmanship was improved at I altitude in both uniforms to varying degrees. At I altitude, staging increased lift and carry task performance in the NBC protective uniform and marksmanship in both uniforms. Possible mechanisms by which staging improves physical work performance include increased cardiopulmonary function ensuing from altitude acclimatization and/or decreased aversive subjective reactions due to familiarity with the stresses associated with the task. After staging to I altitude, although VE was not changed, SpO<sub>2</sub> and O<sub>2</sub> pulse increased, suggesting less cardiopulmonary strain. On the other hand, staging to H altitude increased physical work performance in both uniforms, but in the absence of any measurable physiologic improvement indicative of altitude acclimatization. Likewise, the instruments used to assess subjective reactions (RPE, EDQ, ISQ) did not reveal any beneficial effect of staging on reducing the aversive effects of either I or H altitudes or the NBC protective uniform on physical work performance. The lack of significant improvements in physiologic and subjective responses during physical work following staging may be due to the inability of our instruments and methods to detect small changes which may be the basis for the physical work improvements. Nevertheless, our results substantiate previous reports (Hackett, 1980; Hackett et al., 1976; Hackett and Roach, 1987) that using a staged ascent sustains physical performance at increasing altitude. The current study demonstrated that staging at moderate altitude for 3 days improves physical work and marksmanship performance at I and H altitudes. Moreover, staging's beneficial effects tended to be more pronounced in the NBC protective uniform at I and H altitudes.

This study demonstrated that the decrements in physical work performance caused by wearing an NBC protective uniform (U.S. Army Mission Oriented Protective Posture IV) are greater at I and H terrestrial altitudes than at SL. Further, it demonstrated that staging at moderate altitude improves work performance in the NBC protective uniform at I and H terrestrial altitudes. In addition to decrements in physical work performance, rapid ascent to I altitude degrades marksmanship performance. Again, staged ascent improves marksmanship performance at I altitude. The results of this study support previous U.S. Army recommendations (Department of the Army, Headquarters, TB MED 288, 1975) regarding the employment of a staged or slow ascent to minimize decrements in work performance and extend those recommendations to operations in NBC protective uniforms at I and H mountain altitudes.

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FIGURE 1

Elevation and ascent profile in relation to test schedule.

MA: Massachusetts test site, CO: Colorado test site, SL: Sea Level test,  
 RI: Rapid ascent Intermediate elevation test, SI: Staged ascent Intermediate elevation test,  
 RH: Rapid ascent High elevation test, SH: Staged ascent High elevation test, tvl: travel day.

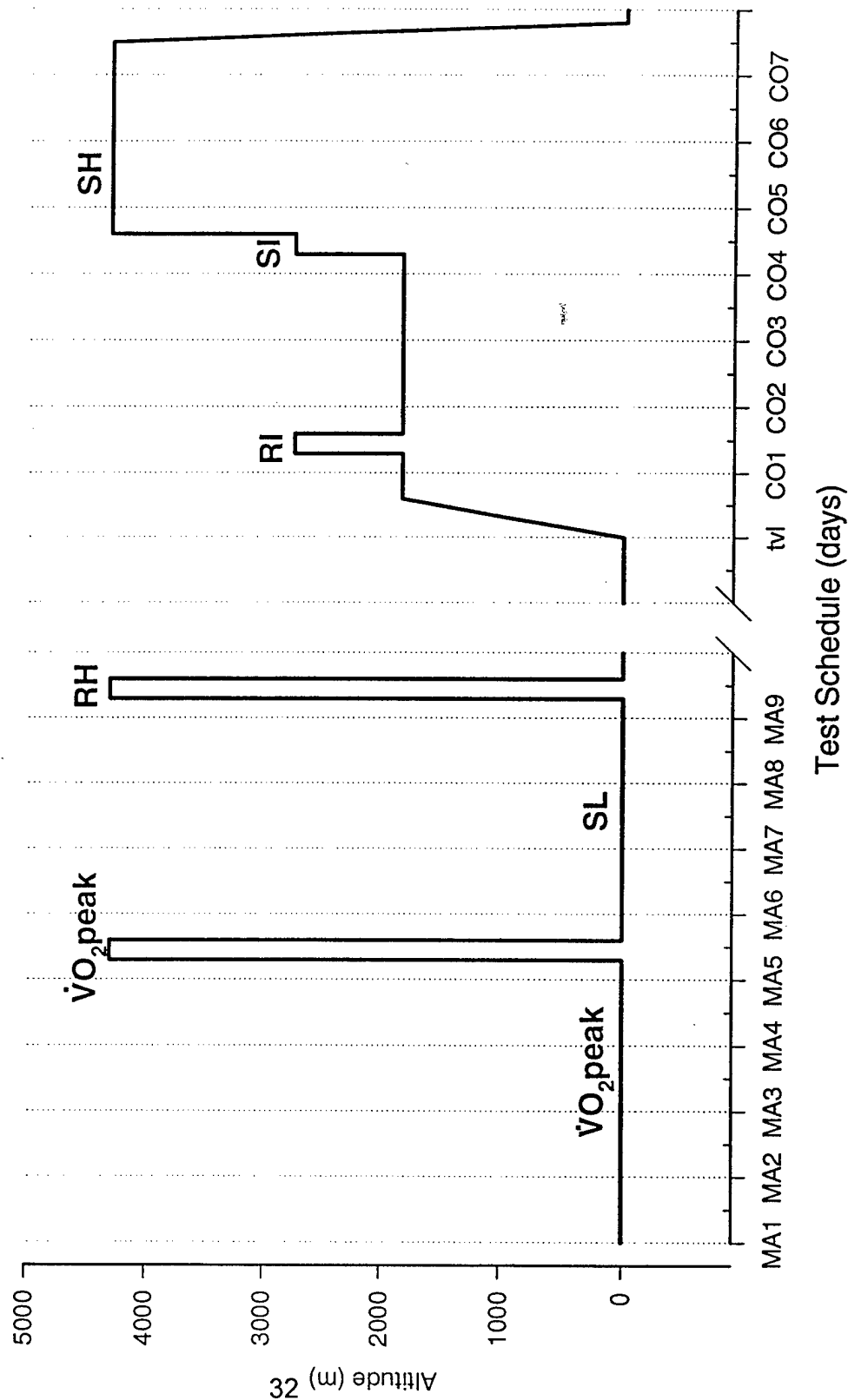


FIGURE 2  
NBC protective uniform induced decrements in pulmonary function.  
Decrement is calculated as % $\Delta$  from PT uniform.

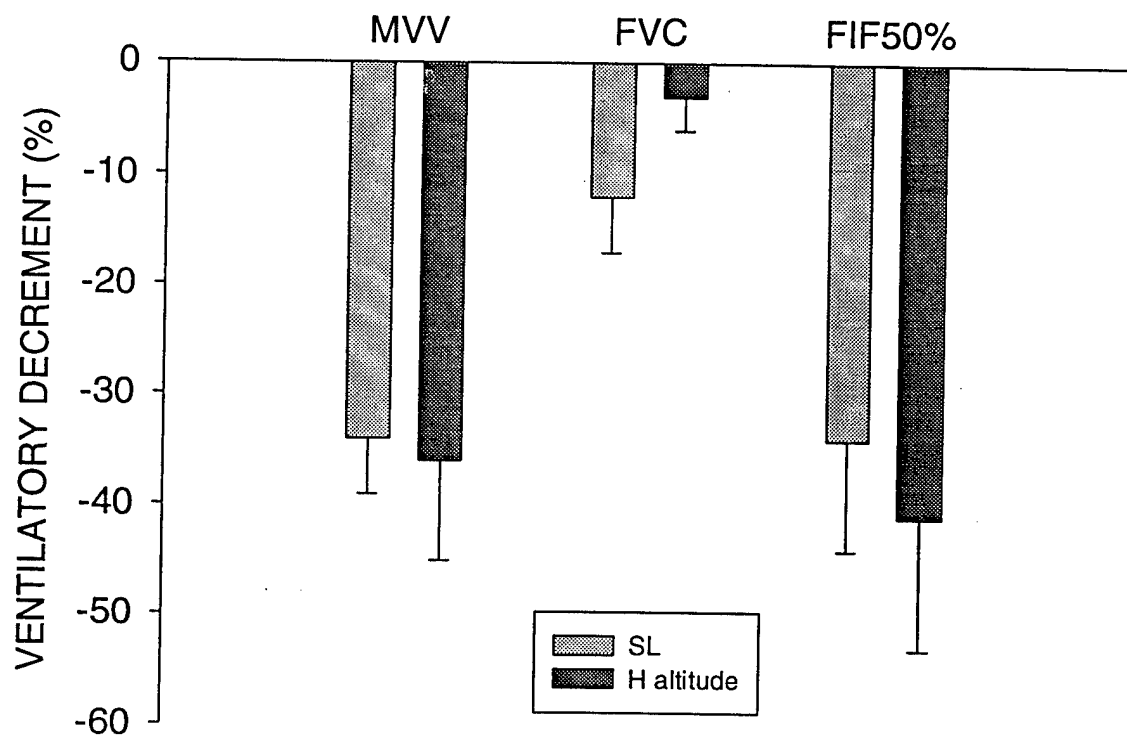


FIGURE 3  
Lift and carry task performance  
at sea level, and intermediate and high elevations  
following rapid and staged ascents.

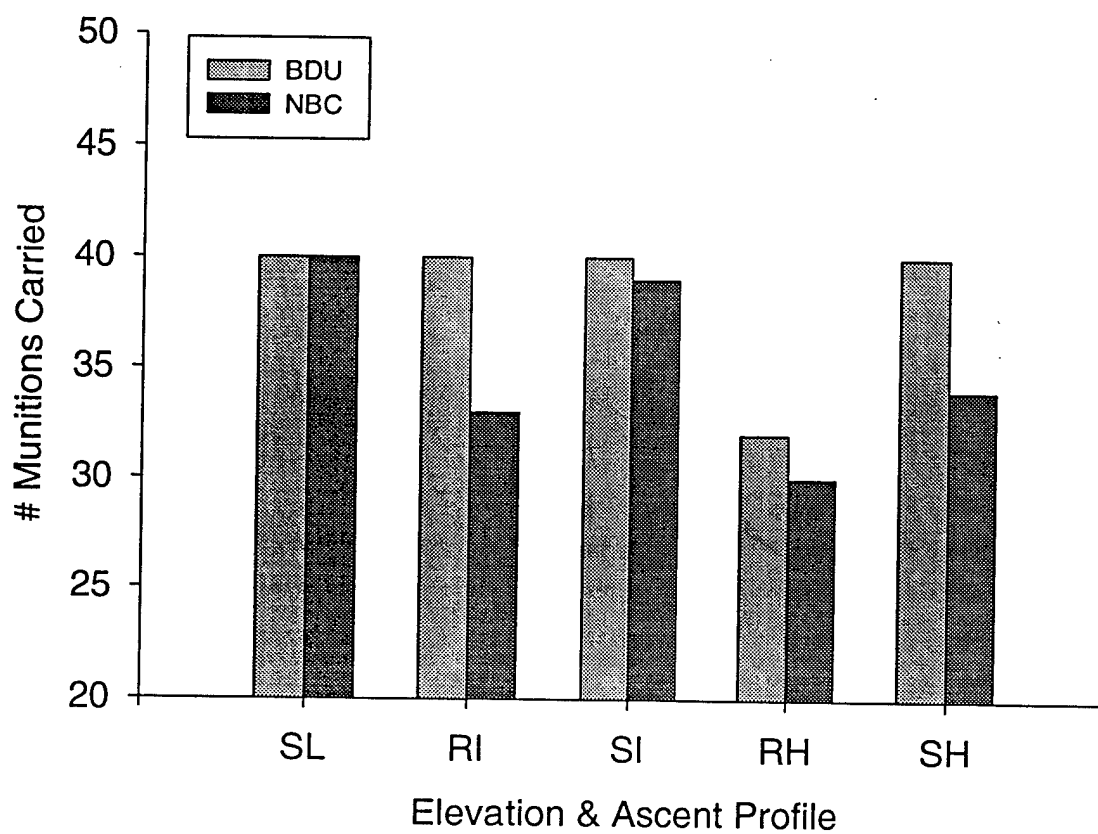


FIGURE 4  
Oxygen uptake during last 6 min of lift and carry task  
at sea level, and intermediate and high elevations  
following rapid and staged ascents.

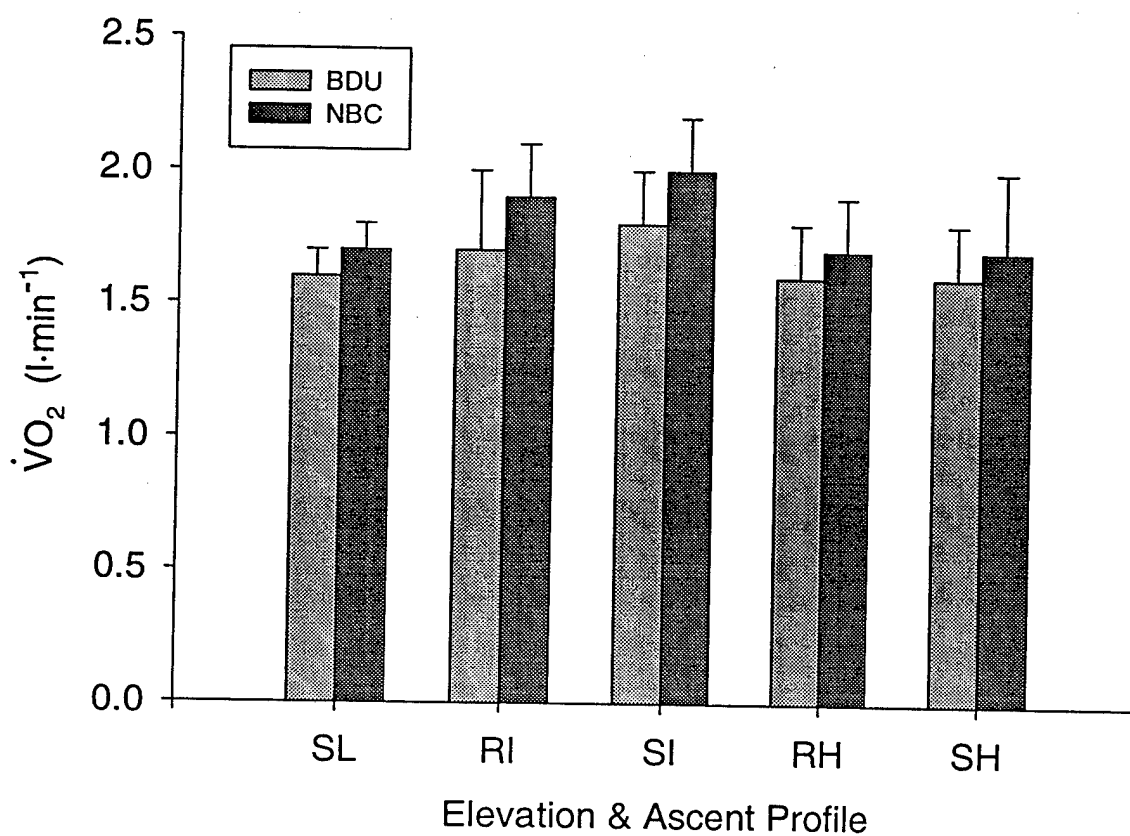


FIGURE 5  
Minute ventilation during last 6 min of lift and carry task  
at sea level, and intermediate and high elevations  
following rapid and staged ascents.

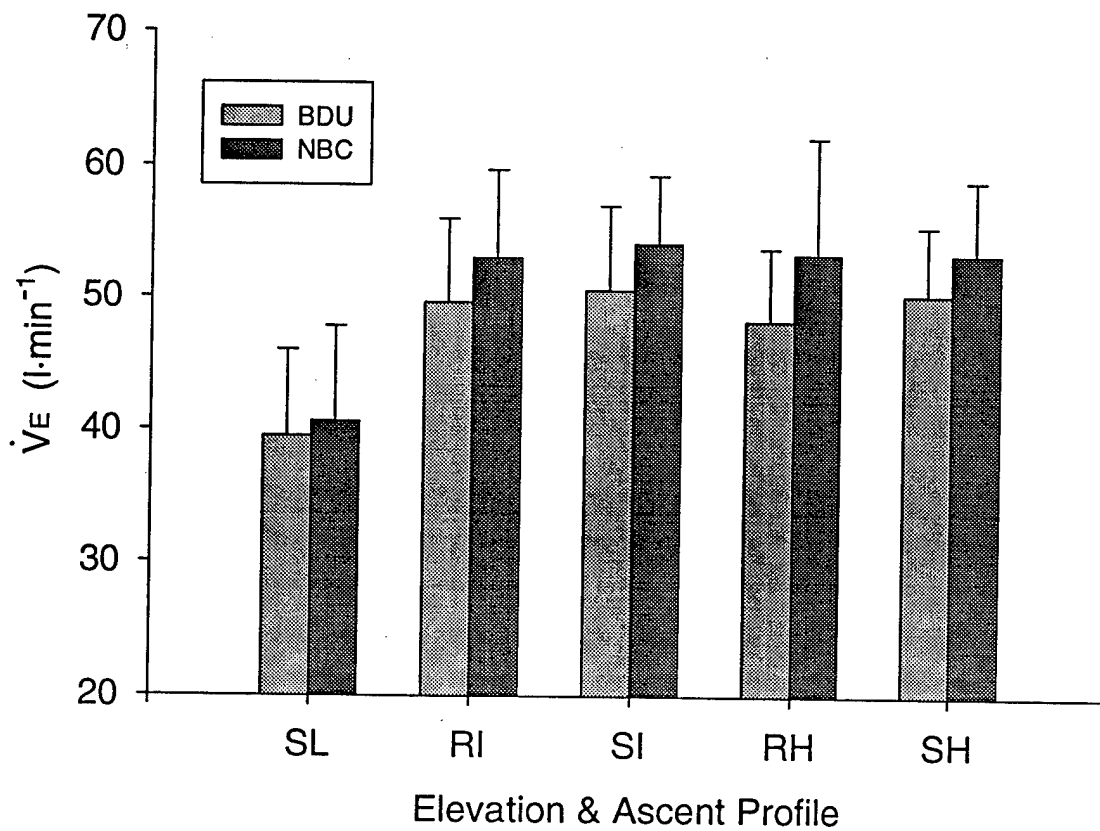


FIGURE 6  
Heart rate during last 6 min of lift and carry task  
at sea level, and intermediate and high elevations  
following rapid and staged ascents (\*p<0.02).

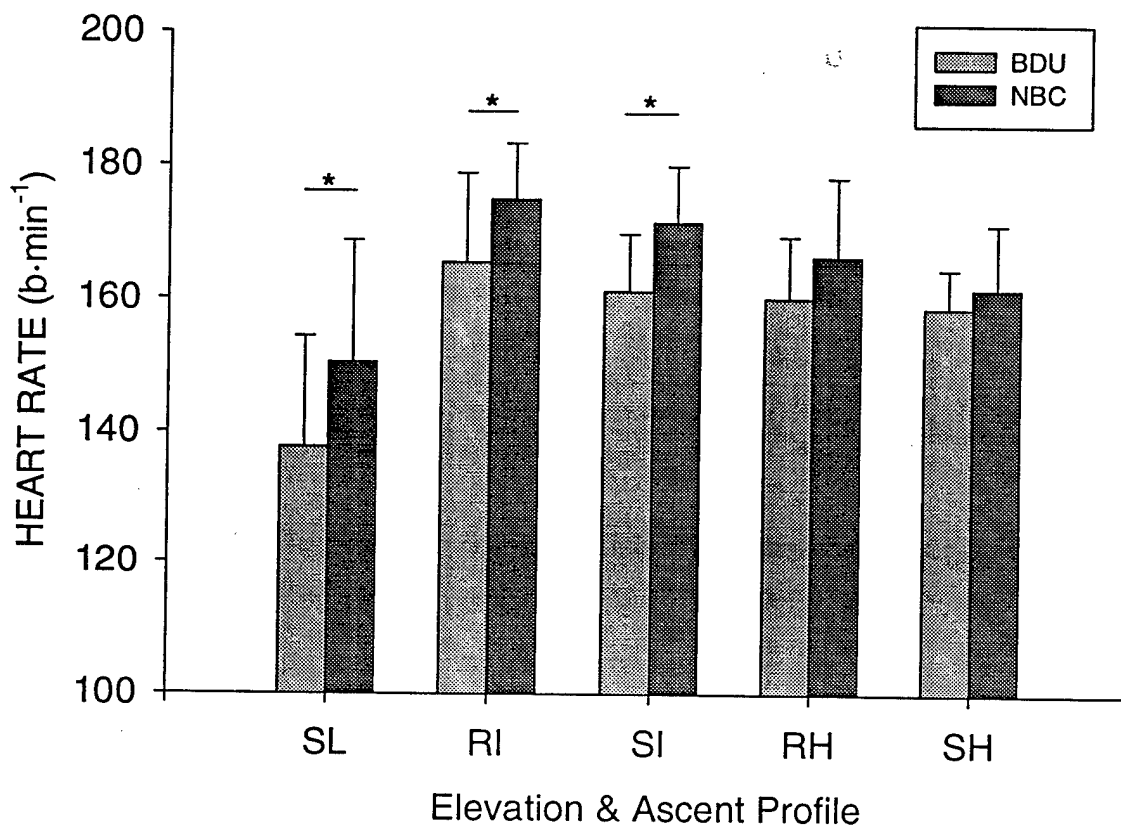


FIGURE 7  
Ventilatory equivalents for oxygen during last 6 min of lift and carry task  
at sea level, and intermediate and high elevations  
following rapid and staged ascents.

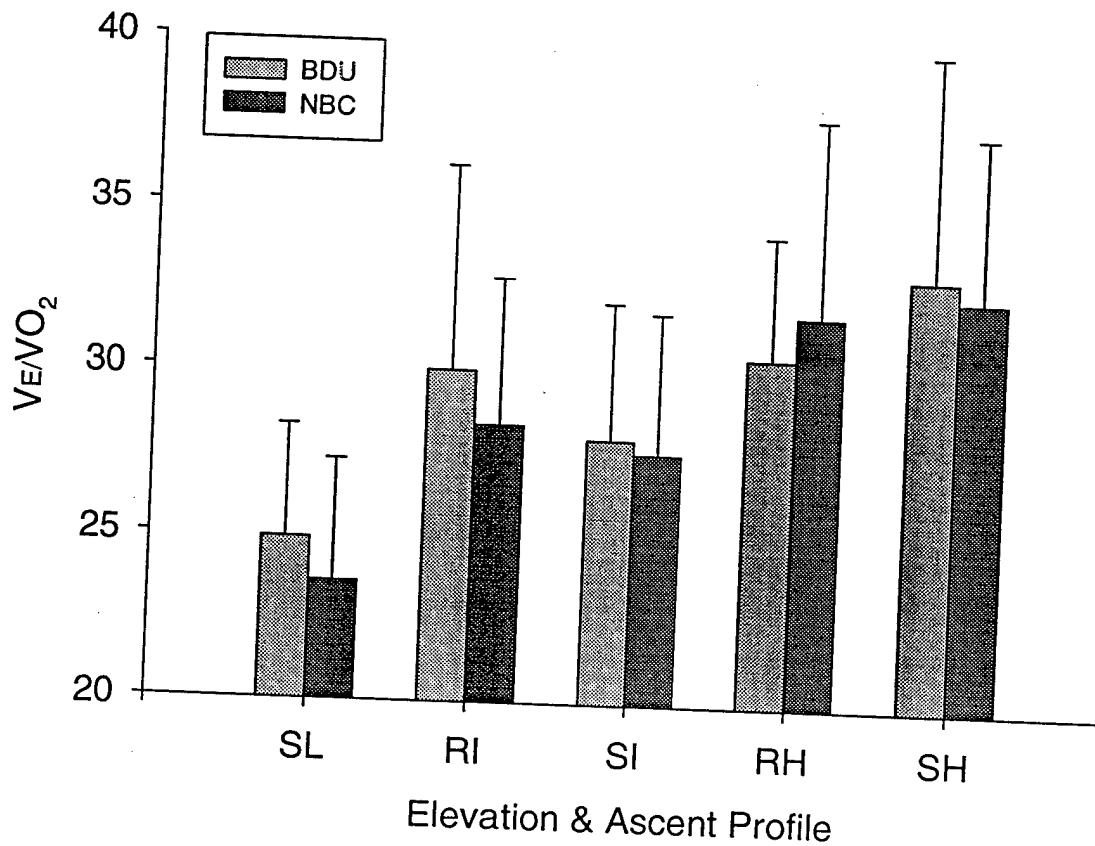


FIGURE 8  
Minute ventilation as a % of MVV during last 6 min of lift and carry task  
at sea level, and intermediate and high elevations  
following rapid and staged ascents.

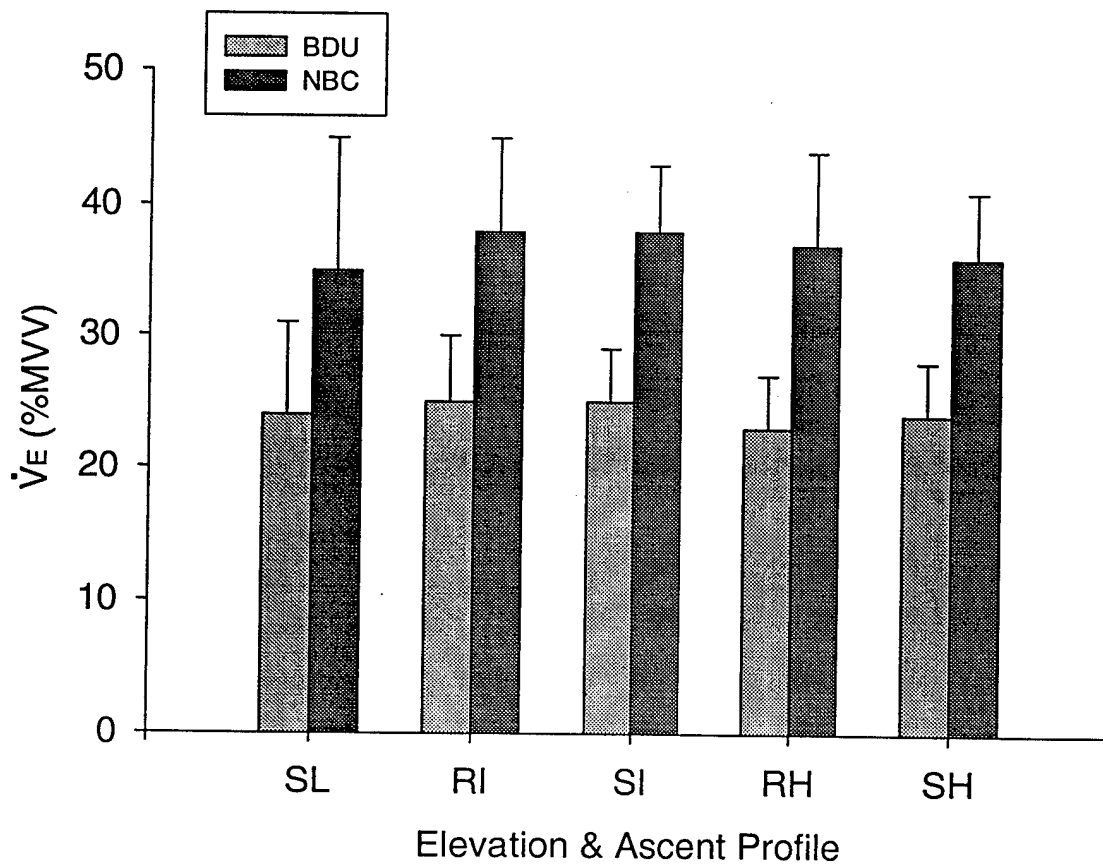


FIGURE 9  
Arterial oxygen saturation during last 6 min of lift and carry task  
at sea level, and intermediate and high elevations  
following rapid and staged ascents (\*p<0.05).

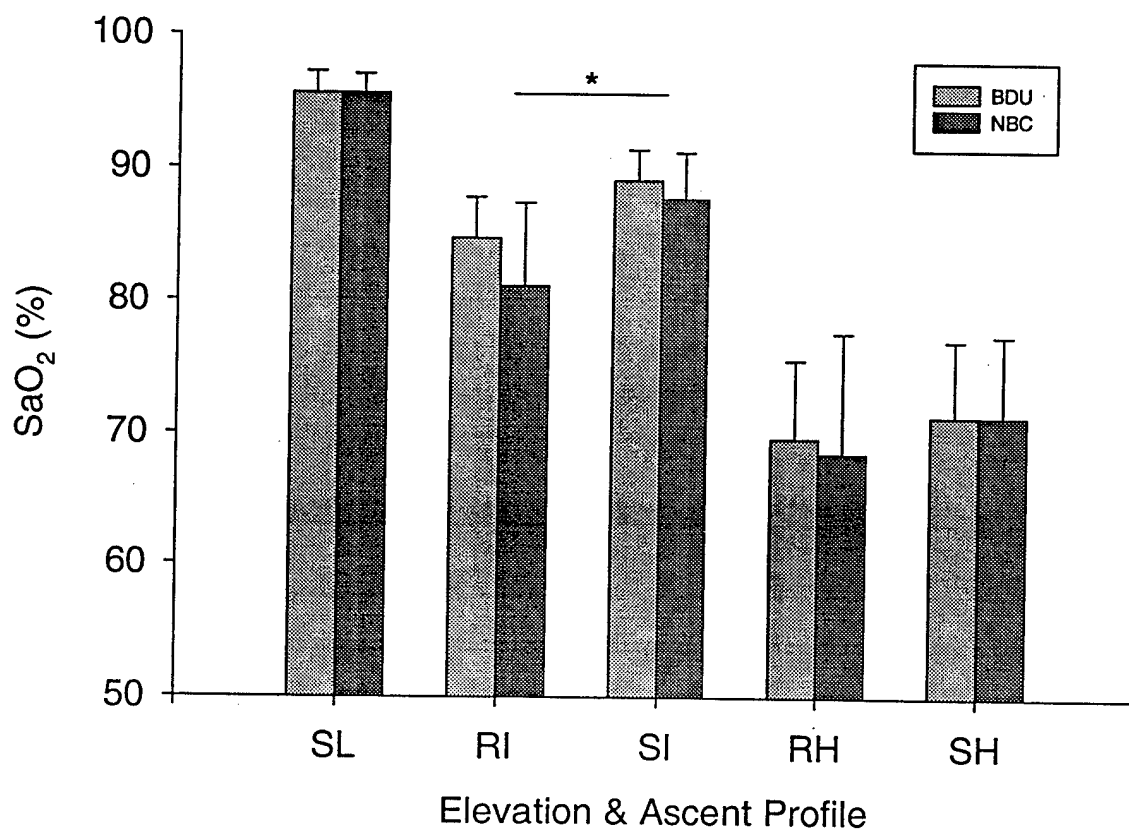


FIGURE 10  
Oxygen pulse during last 6 min of lift and carry task  
at sea level, and intermediate and high elevations  
following rapid and staged ascents (\* $p < 0.02$ ).

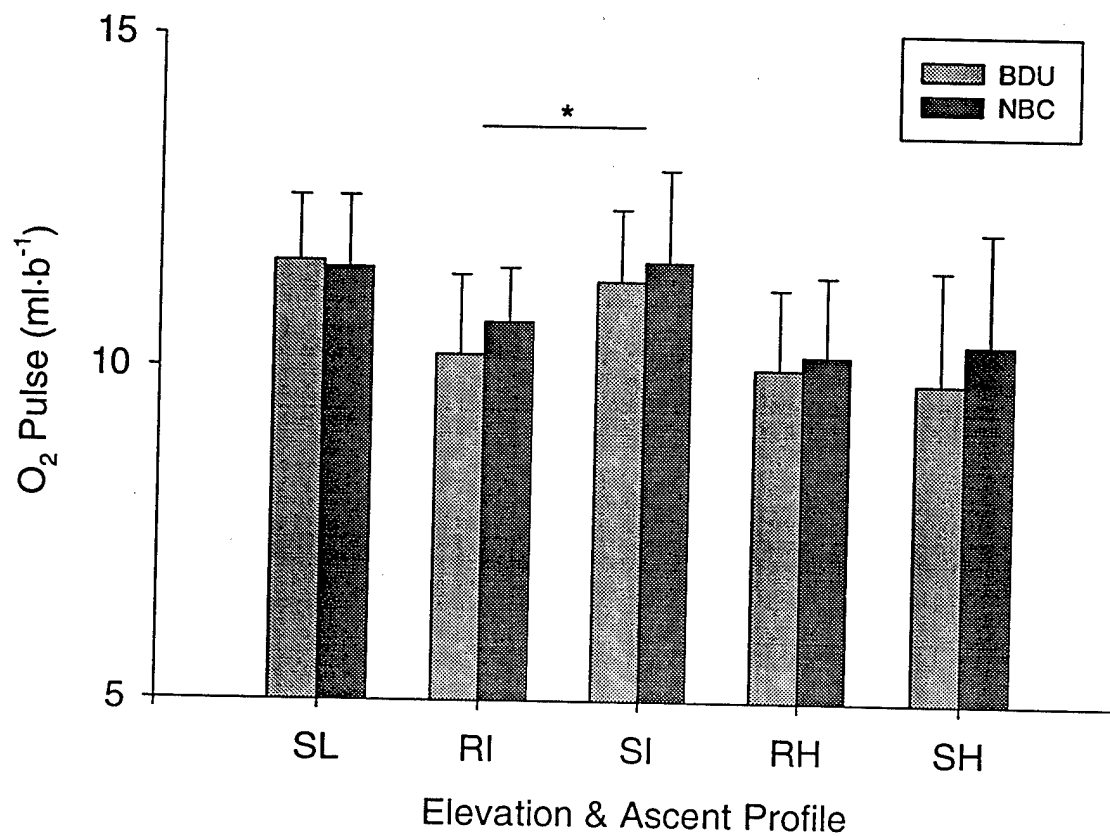
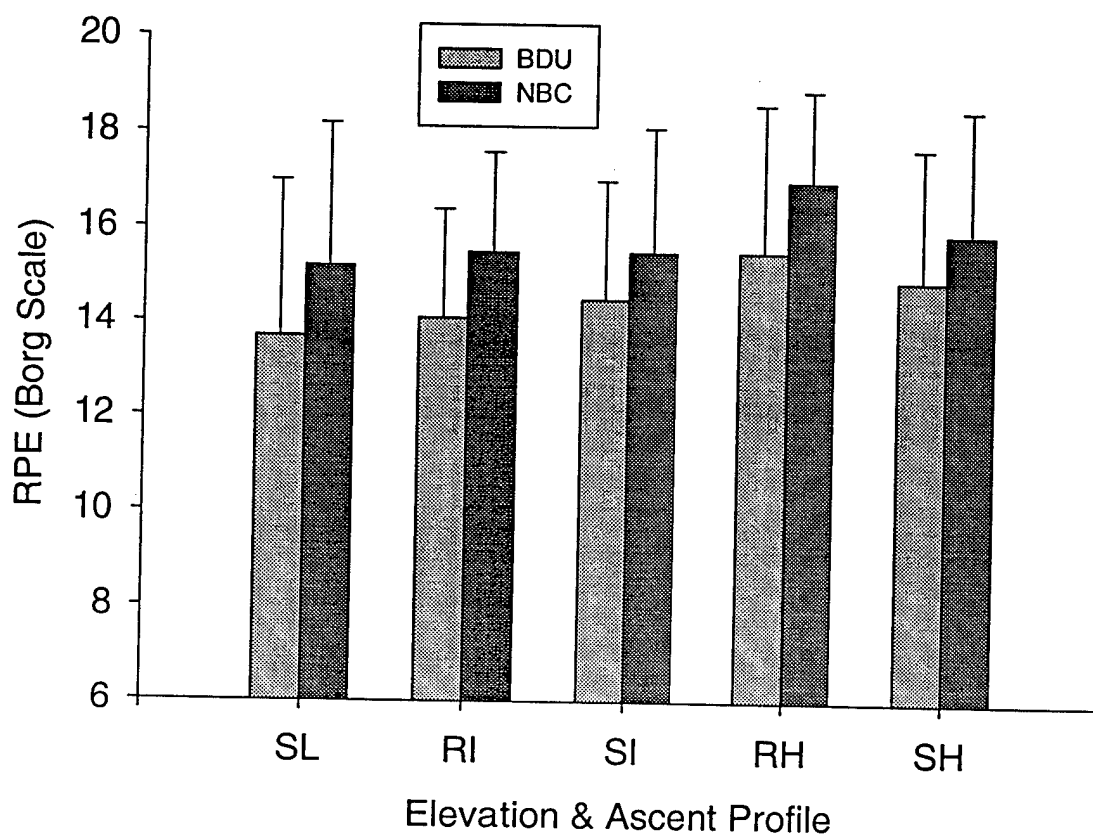
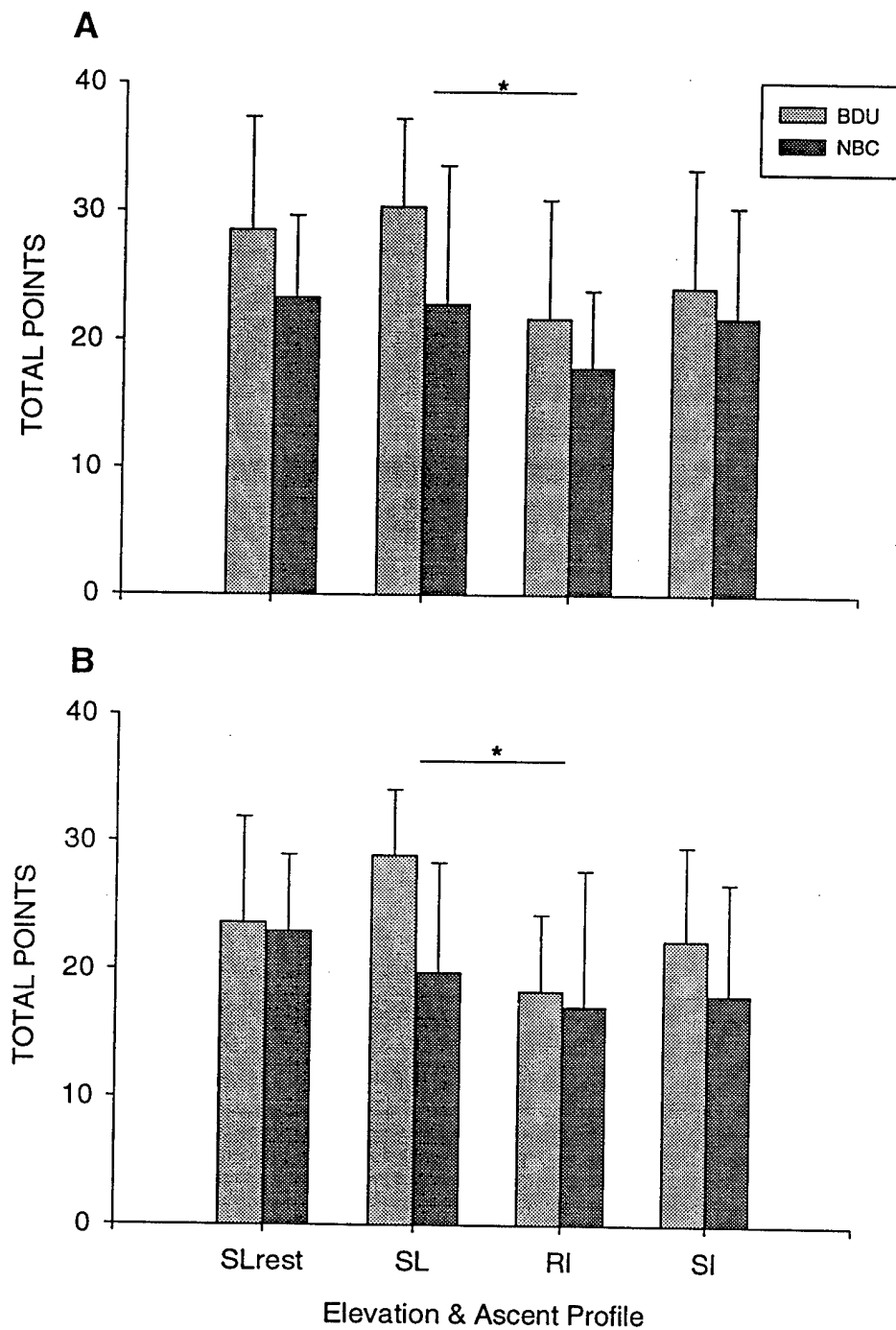


FIGURE 11  
Rated Perceived Exertion during last 6 min of lift and carry task  
at sea level, and intermediate and high elevations  
following rapid and staged ascents.



**FIGURE 12**  
 Marksmanship performance (A: untimed, B: timed)  
 at sea level and intermediate elevation  
 following rapid and staged ascent.



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